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GAMMA-RAY ASTRONOMY WITH A DIGITIZED SPARK CHAMBER

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ABSTRACT

A series of high altitude balloon flights to look at possible point sources of cosmic gamma radiation have been made beginning in September 1966. The heart of the detector system used in these investigations consists of a 32 level, 256 wire per level, magnetic-core digitized spark chamber, with thin (0.02 radiation length) high-Z pair-producing plates between each level. This spark chamber is surrounded by a bell-shaped plastic scintillator dome and is triggered by a coincidence between a thin central scintillator and a Cerenkov counter in anticoincidence with the dome. This device is flown in an oriented balloon gondola. Results related to several potential gamma-ray sources have been obtained in a series of three flights. Upper limits for the flux of γ-rays above 30 MeV of (2 to 4) x 10^{-5} $(cm^2 sec)^{-1}$ have been established for Sco X-1, Sgr SR-1, Sgr SR-2, Sgr SR-3, the Kepler Supernovae (Oph XR-1), the galactic center, the moon, and the quiet sun. Somewhat less severe limits have been set for Centaurus-A and Taurus-A.

INTRODUCTION

In recent years, there have been several attempts to detect celestial gamma rays, but there is still no certain measurement of a flux of high-energy gamma rays from a point source. In spite of this negative result, very high-energy astronomy remains as a field of great interest because it can provide a means of detecting many of the major energy transfers occurring in the universe. In addition to revealing the presence of very energetic electrons through their synchrotron, bremsstrahlung, and inverse Compton radiation, high-energy gamma rays reveal the presence of the pi mesons formed in nuclear interactions and other high-energy processes.

The experiment to be described here represents the early balloon version of a detector system which was developed primarily for satellite application, wherein the limit of source detection is not hindered by a high atmospheric background and relatively short exposure times. The detector is a digitized spark-chamber telescope sensitive to gamma rays in the energy interval from about 30 MeV upwards. It has been flown several times from Mildura, Victoria and Holloman, New Mexico.

EXPERIMENTAL APPROACH

In order to provide the selectivity and sensitivity to do astromony, a gamma ray telescope must discriminate against charged particles with a high efficiency, give enough information to select gamma rays from other neutral events, permit accurate determination of the gamma ray's arrival direction, provide some means of estimating their energy, and have a reasonably large detection probability. With these criteria in mind the detector system shown in Fig. 1 was developed. The large plastic scintillator anticoincidence dome and the directional Cerenkov counter are employed to discriminate against charged particles and to restrict the analysis to downward moving particles. The spark chamber satisfies the need for a large volume, high information-content detector to permit selection of the gamma rays and measure the properties of the electron-positron pair. The central plastic scintillator in coincidence with the Cerenkov counter and in anticoincidence with the plastic dome provides the data needed to determine whether the spark chamber should be triggered.

The spark chamber and its associated electronics are discussed in detail in another article (Ehrmann et al., 1967); so only the principal features will be given here. As Fig. 1 shows, the spark chamber consists of two units separated by the central scintillator. Each unit consists of a series of fifteen plates and sixteen wire-grid modules. Each of the modules is a frame-wire assembly consisting of two orthogonal sets of 128 wires each. One orthogonal wire grid serves as the high voltage plane of the modular unit, the other as the ground plane. All of the wire modules are identical except the bottom one in each chamber, in which the wires run at an angle of 45^o with respect to all of the others. The 45^o grid permits the removal of the ambiguity related to which x reading of two is associated with which y reading when two tracks are present.

Each of the 30 pair producing plates consists of .02 radiation lengths of gold plated unto a .002 radiation length base of aluminum providing a high-Z plate which is thin enough so that the character of the event is not masked by a thick converter or absorber, and the direction of the incident gamma ray can be measured well. At the same time, the large number of plates retains a reasonably large detection efficiency. Finally, some information on the energy of the electron and positron can be extracted from the multiple coulomb scattering in the plates.

Each of the grid wires in the spark chamber thread a magnetic core, which receives and contains its datum of information when the high voltage is pulsed to the chamber grids. The location of the set cores is recorded on tape and telemetered.

The gamma ray telescope is placed in a gondola at a fixed angle with respect to the vertical, and the gondola is oriented with respect to the geomagnetic field to an accuracy of about $\pm\frac{1}{2}^o$ after the balloon reache ceiling. The orientation is accomplished with a gas jet system which is controlled by information from a magnetometer and a rate gyro.

DATA REDUCTION AND RESULTS

The first step in the data reduction is the analysis of individual events. Since the flights reported here were among the first in a series, the data was reduced both manually and by computer.

In the manual analysis, the type and quality of each event is studied using a full computor print-out displaying each core. Clear γ-ray events which display both an electron and a positron are selected together with possible γ-ray events wherein there is only one track beginning somewhere in the detector. Measurements to determine the direction of the original γ-ray, the opening angle of the electron-positron pair, and the energy of the electron and positron are made. Fig. 2 shows six examples of acceptable gamma-ray events. The great majority of the unacceptable events are ones where tracks are coming from the wall of the chamber and presumably result from interactions of neutral particles in the wall.

In the automatic processing of the balloon-flight spark chamber data, events are examined by machine, categorized and, if accepted, fitted by the least-squares method to a photon trajectory in chamber coordinates; aspect, position, and time data are then automatically used to determine the celestial arrival direction of each photon, and sky maps of photon flux are constructed.

At high energies where the opening angle between the pair is very small, the accuracy of the estimate of the arrival direction is determined solely by the uncertainty of the balloon orientation information, or about a half a degree, and lessens as the photon energy decreases, reaching 2.0 degree, for a 100 MeV photon. Below this energy, it is possible to determine the energy of each electron of the pair by analysis of the multiple scattering of the electrons in the plates sufficiently well so that the uncertainty in arrival direction does not increase in size beyond three degrees down to the 30 MeV low energy limit of the detector.

The energy of the primary photon is determined from the opening angle between the electron and positron and from coulomb scattering in the thin plates. The details of this analysis and the determination of the energy spectrum of the observed gamma rays, which are known to be primary atmospheric secondaries, will be discussed in a later paper.

If only the upper half of the chamber is considered as being sensitive to pair production which will be accepted for analysis, an area collection time factor of 7.8 cm^2 sec is obtained. With an average live time of 50% and a typical efficiency of .19, one gamma ray corresponds to $1.4 \times 10^5/cm^2$ sec. The general background observed at the balloon altitude assuming a typical detection efficiency of 0.19 is about $4 \times 10^{-3}/cm^2$ sr sec. For a point source and a cone of uncertainty of 2^o radius, the flux contributed by the background is $1.5 \times 10^{-6}/cm^2$ sec.

An analysis of the data shows no obvious gamma ray source in the field or view during any of our flights. Table I lists what are felt to be the most likely gamma ray sources for the regions of the celestial sphere observed and lists 95% confidence upper limits to the flux of high energy ($\gtrsim$ 30 MeV) gamma rays from these objects. These limits were determined by calculating the maximum flux which together with the known background had more than a 5% chance of yielding the number of gamma rays observed or less in the core of uncertainty. The relatively high limit on Centaurus A is due to 4 gamma rays whose arrival directions were within the cone of uncertainty. The average number for this flight was 1.2. This number of observed gamma is not sufficiently important to justify any consideration of having possibly seen a source. The relatively high upper limit on Taurus A results from a short exposure time, and the limited date handling capability on that particular flight.

For the future, we plan to fly this unit again on balloons with an inproved orientation system, which will track a source. The main objects to be studied will by Cygnus and Taurus A. We also have plans for building a much larger system to be flown on a satellite.

TABLE I Gamma Ray Point Source Upper Limits

(95% Confidence)

SOURCE	LIMIT (cm^{-2} sec^{-1})
Sco X-1	3.9×10^{-5}
Kepler Supernovae (Oph XR-1)	3.9×10^{-5}
Galactic Center	3.9×10^{-5}
SGR XR-1	3.9×10^{-5}
SGR XR-2	3.9×10^{-5}
SGR XR-3	3.9×10^{-5}
Centaurus A	9.5×10^{-5}
Quiet Sun	2.4×10^{-5}
Moon	2.4×10^{-5}
Taurus A	1.7×10^{-4}

REFERENCE

Ehrmann, C. H., C. E. Fichtel, D. A. Kniffen, and R. W. Ross, submitted to Nuclear Instruments & Methods.

FIGURE CAPTIONS

Fig. 1 Schematic view of gamma-ray spark chamber detector system.

Fig. 2 Digital printouts of six gamma-ray events from a balloon flight over Australia. Four lines of dots not representing spark chamber wires have been artifically inserted into the center of each picture to compensate for the gap in the spark decks where the thin scintillator exists. The X-Z and Y-Z projections of each event have been compressed to the extent that the 128 wires in each row are displayed in the form of 64 symbols: dots represent the absence of sparks, U represents two sparks, and L or J represent a single spark on the left or right of the pair, respectively.

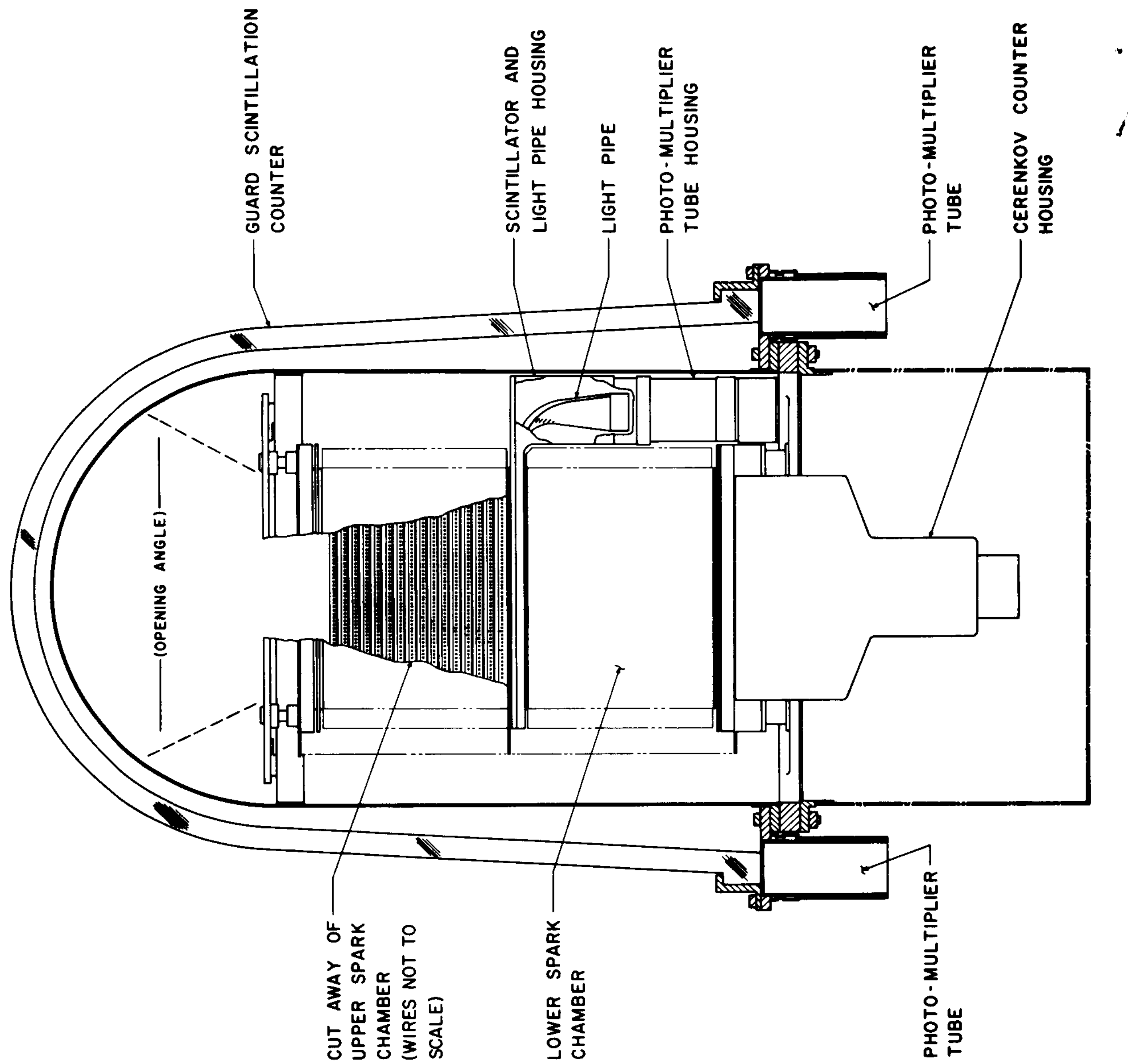
GUARD SCINTILLATION COUNTER
SCINTILLATOR AND LIGHT PIPE HOUSING
LIGHT PIPE
PHOTO-MULTIPLIER TUBE HOUSING
PHOTO-MULTIPLIER TUBE
CERENKOV COUNTER HOUSING
(OPENING ANGLE)
CUT AWAY OF UPPER SPARK CHAMBER (WIRES NOT TO SCALE)
LOWER SPARK CHAMBER
PHOTO-MULTIPLIER TUBE

Figure 1

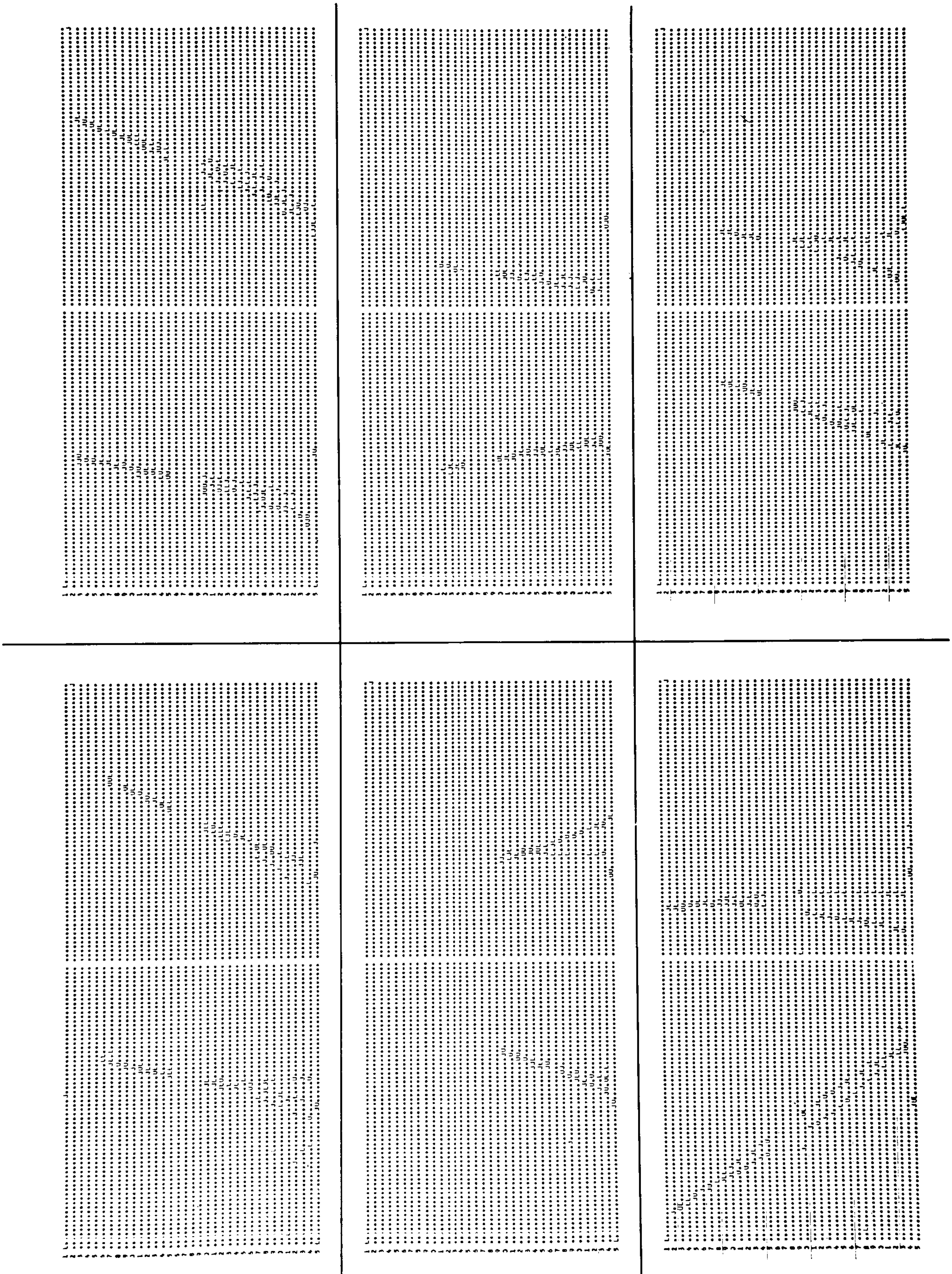

Figure 2